THE PERSISTENCE OF PLANT AND ANIMAL LIFE UNDER CHANGING CONDITIONS OF ENVIRONMENT.[1]

BY PERSIFOR FRAZER.

DANA, in the Introduction to his Manual of Geology (1874), thus distinguishes between the Plant and Animal Kingdom, on the one hand, and the Crystal Kingdom on the other hand:

"The plant or animal, (1) endowed with life, (2) commences from a germ, (3) grows by means of imbibed nutriment, and (4) passes through a series of changes and gradual development to the adult state, when (5) it evolves new seeds or germs, and (6) afterwards continues on to death and dissolution. It has, hence, its cycle of growth and reproduction, and cycle follows cycle in indefinite continuance.

"The crystal is (1) a lifeless object, and has a simpler history; it (2) begins in a nucleal molecule or particle; (3) it enlarges by external addition or accretion alone, and (4) there is hence no proper development, as the crystal is perfect, however minute; (5) it ends in simply existing, and not in reproducing; and (6) being lifeless, there is no proper death or necessary dissolution."

In pursuing the subject more in detail this author states of both plants and animals that they "have the fundamental element of their structure, visible cells, containing fluid or plastic material, instead of invisible molecules."

As to this it may be said that while there are some reasons for believing, with our present knowledge of the nature of light, that the microscope will never reveal to us a single molecule, such a revelation is not at all impossible when one considers the gigantic strides which have been made in subduing the phenomena of nature to aid us in penetrating her secrets; but even if it be true that we shall never see a single molecule, it is not yet proven that a single molecule forms the unit of mineral building. There are

[1] An address delivered before the Pennsylvania Horticultural Society, May 20, 1890.

some reasons opposed to this view mentioned by Dr. Hensoldt in an interesting article on Crystallogenesis (*Am. Geologist*, May and June, 1890). If we could magnify objects 30,000 diameters, and not thereby reduce the illumination too much, we might see a single molecule. At present the limits thus far reached are some 1600 diameters. "But," Dr. Hensoldt says, "the particles of which crystals are composed can be clearly discerned with a $\frac{1}{10}$ inch objective,—very rarely in the finished crystal, but whenever a substance is examined under the microscope during the process of crystallization, and wherever the operation of crystalline forces can be observed under high powers of magnification. There are reasons for believing that each of these visible particles is an aggregate of molecules, just as a molecule is an aggregate of atoms, and that no single molecule is capable of manifesting polar forces of sufficient energy to enable it to play a part in crystalline economy. . . 'The angular hypothesis' which maintains that the fundamental force of a crystal is determined by the shape of its integral molecules, has very few adherents now . . . On the other hand, the spheroidal form of the planets, the tendency of fluids to assume the spherical shape and the mechanical facilities which the hypothesis of rounded particles offers in the grouping of molecules have induced later inquirers to adopt almost unanimously the views of Wollaston and Hooke. We are now in position to show . . . that molecules must be more or less spherical, and in the case of augmented molecules, . . . or the minutest parts of which crystals are composed, we have abundant direct proof of this, as their forms are revealed to us by a magnification of less than 1500 diameters."

Dana continues: "(2) The living being enlarges by means of imbibed nutriment through a process of evolution; and not by mere accretion or crystallization."

This use of "evolution" is vague, and an enlargement by other means than mere accretion is unsupposable. Whether the accretion is from without or within, exogenous or endogenous, there can be but one way of lengthening or widening or deepening an object, and that is by adding matter to it or by stretching further apart the particles of matter which it already has.

This is as true of a plant or animal as it is of a crystal, and until we learn what is the procedure in the act of growing manifested by plants and animals, we cannot assert that it is different from that in crystals. The framework of some living organisms is made up of minute crystals of carbonate of lime. It seems quite possible that the minutest component parts of either the cell or the perfectly visible crystal are crystalline, and that the next larger components, both in crystals and in organisms, are spheroidal bodies more or less resembling cells.

Another strong reason for believing that the smallest parts of organisms are crystalline in character, is the action upon them of polarized light.[2]

Without going more minutely into the explanation of these curious phenomena, it will be sufficient to say that bodies which are built up in such a manner as to exhibit greater density in one direction than another are said to be under the influence of polar forces of different degrees. Such building up is crystalline, and is apparent by the effect which the structure exerts on polarized light; and almost if not all organic solids show these effects.

Dana continues: "(3) It has the faculty of converting the nutriment received into the various chemical compounds essential to its constitution, and of continuing this process of assimilation as long as the functions of life continue; and it loses this chemical power when life ceases."

The crystal lives on what it can absorb from the liquids or semi-liquids, and from the gases surrounding it—probably never from the solids. In this it resembles the living thing.

Moreover, it separates out of a solution containing many things the materials which it needs to continue the growth of itself, and rejects the rest, either pushing them aside or enclosing them as foreign bodies within its own structure.

As to its losing this power when life ceases, the crystal's life or growth may be said to last so long as there is a menstruum in which it can derive material for its further accretions, and to cease when this menstruum is withdrawn. But it can be resumed

[2] As pointed out by the speaker in a lecture before the International Electrical Exhibition in 1884.

again at any time that it is placed under similar conditions, and in the meantime it may remain just as it was left when its growth ceased. This seems to me to offer a better distinction between the organic and inorganic than most others, viz: that when the force which produced the first and sustains it by constant replacement of matter ceases, it cannot again be resumed with the same results in the same being, but in the inorganic world this is possible.

Dana continues: "(4) The living being passes through successive stages in structure and in chemistry, from the simple germ to a more or less complex adult state, and finally evolves other germs for the continuance of the species; instead of being equally perfect and equally simple in all its stages, and essentially germless."

It would be expected that the crystal world would be found to resemble more nearly the less organized end of the organic world, and we should look for analogies to the simple amœbas. These are but drops of jelly in their simplest forms, which grow in size by absorption of what passes through them, and which break up into fragments, each of which becomes a new nucleus for a similar organism.

If these be considered germs, then the detached fragments of a large crystal which form new nuclei of similar crystals in a solution containing the materials out of which the chemical substance necessary to their being is obtained, are also germs. It is well to recall also that, though there may be innumerable other substances in the same solution than those entering into the formula of the crystallizing mineral, these latter will be excluded, and those which are necessary will be assimilated as truly as the stomach of animals or the organs of plants assimilate their nutriment.

In the more special distinctions which this author makes between plants and animals, there is nothing to arrest the conclusions which seem forced upon us by a consideration of the above general characteristics. These distinctions have relation to the absorption by the plant of carbonic acid, and by the animal of oxygen; of manufacturing organic food for the animal, by the

plant, from inorganic material; etc, etc., which do not concern the main question of the essential continuity of inorganic with organic force, and the separation of the phenomena of the latter from those of the former by an indefinable line. No hard and fast line can be drawn to separate animal from plant, and none to separate plant from crystal. The force which is the cause of production and of change seems as if it were simply modified to suit the various structures which it builds. The material in all three kingdoms of nature is without doubt the same. One force —one matter—is foreshadowed here.

It will be advisable to look a little more closely at this material. The most generally accepted hypothesis of the evolution of the solid earth on which we live begins with La Place's celebrated generalization of the condensation of tenuous material,—first to vapor; then to liquid; then to solid, at an intensely high temperature; and finally by cooling to the globe that we know.

Dr. T. Sterry Hunt (Chem. and Geol. Essays) has taken up the history where La Place leaves it, or at the stage where the in great part molten earth is covered by a thin shell of rock, like lava or basalt, upon which descend acid rains containing hydrochloric, sulphuric, and nitric acids, hitherto kept in suspension by the intensely high temperature. The crust on which these rains descend would necessarily be made of the lightest elements combined together; the heaviest would be found near the centre of the earth.

These lightest materials, which while in fusion floated on the rest like an ocean, would consist of silica and the alkalies and alkaline earths, with some of the rarer elements. On this subject a recently published memoir of Prof. F. W. Clarke, Chemist of the U. S. Geological Survey, is extremely interesting. Prof. Clarke has for the first time systematically investigated the composition of the crust of the earth for a depth of ten miles from the surface, by comparing a great number of analyses of the various rock strata of different parts of the world with each other.[3]

[3] Relative Abundance of Chemical Elements, by Frank Wigglesworth Clark , Philo sophical Society of Washington Bulletin, Vol. XI., pp. 131–142.

From the mean of 880 analyses he finds that the solid crust constitutes 93 p. c.; the ocean 7 p. c.; and the air much less than 1 p. c. by weight (so that the latter is added as a slight correction applied to the ocean).

Taking these figures, he has calculated from the above 880 analyses, made in all parts of our own country and Europe and throughly combined and sifted, the following curious table of the frequency of the various elements. He adds that the fifty odd elements not included here can hardly aggregate 1 p. c. altogether.[4]

	P. C.
Oxygen	49.98
Silicon	25.30
Aluminum	7.26
Iron	5.08
Calcium	3.51
Magnesium	2.50
Sodium	2.28
Potassium	2.23
Hydrogen	0.94
Titanium	0.30
Carbon	0.21
Chlorine and Bromine	0.15
Phosphorus	0.09
Manganese	0.07
Sulphur	0.04
Barium	0.03
Nitrogen	0.02
Chromium	0.01
Total	100.00

The effect of acid rains upon this slag-like material can easily be predicted, and the prediction agrees with the facts as observed. Thus the deduction from La Place's hypothesis would lead to a soil and air composed as we observe them, and the growth of all

[4] See Chem. and Geol. Essays, pp. 35–47.

things would necessarily be by accretion from the elements which predominated in this soil and atmosphere. This is also what we observe.

Some reasons for believing that life is simply one manifestation of force acting upon matter has been alluded to, but there are many other reasons. The demonstration of the correlation and conservation of force, by Graham, Helmholtz, Meyer, Joule, Tyndall and others, in the early sixties marks an epoch in the science of physics. Since the date of this beautiful generalization it has been the practice to calculate all forms of force in terms of heat or heat-units; and many experiments have shown that these heat-units were expended in carrying on the various life processes, precisely as they are in raising water into steam, and cooling the steam again into water by converting part of its heat into the mechanical motion of the parts of a machine.

Regarding an animal as a machine, and its food as the fuel to drive this machine, an approximate calculation has been made of the directions in which the combustion (or assimilation) of the food is employed during the daily use of their organs by animals, and the calculation has been found to agree quite closely with observed facts. It may be safely predicated, therefore, that the force which builds up the plant or animal is calculable in so many heat-units expended to so much work of this kind performed; i. e., to build an inch of sugar cane, as much force is required as would be represented by the burning of a given quantity of coal or wood, and the conversion of the heat thereby obtained into mechanical motion, etc. But the production of these heat-units must depend upon the ease with which certain elements or groups of elements can be broken up and formed into other groups; for this change, called chemical change, always results in the development of heat or its equivalent work. Keeping this fact in view, it is not difficult to understand why the bodies of plants and animals, which require for their very existence that these changes should be continually going on, should be composed of groups of elements easily broken up and re-formed, and of elements, too, which are known as combustibles, or those which greedily seek out and combine with oxygen.

The present state of our planet is this: First, an ocean of atmosphere resting on the surface of the globe, in which exist myriads of living things, composed largely of carbon and hydrogen,—both elements that combine with oxygen, evolving an immense number of heat-units These elements, carbon and hydrogen, while combining together, do so in such a manner that the combinations are easily broken up in presence of the oxygen, for which they have a stronger affinity. "Oxygen is absorbed and carbonic acid evolved in germination, at the birth of the young plant, and in flowering when it arrives at an adult state. In both instances starch is oxidized and converted, first into dextrine, and then into sugar for the nutriment of the young embryo, stamens, and pistils, and these processes are accompanied by a development of heat.

"The respiration of the cotyledonary leaves of the embryo, and of the corrolline envelope of the stamens and pistils, is, in every respect, a true oxidation or combustion of the store of saccharine matter, accompanied by the evolution of carbonic acid.

"Respiration is absolutely essential to the growth of plants, as well as animals."[5] It is true that the leaves of plants under the influence of sunlight decompose the carbonic acid which results from the vital processes, and unite with the carbon in the air; a process not found in the animal economy: but it is nevertheless true that combustion of carbon to carbonic acid and hydrogen to water by the union of these two elements with the oxygen of the air proceeds equally with plant and animal, and is the source of that heat which constitute their vital force.

Thus far it has been indicated that the plant and animal are such structures as are adapted to exist on a soil of silica, alumina, lime, the alkalies, iron, and a few other materials, bathed in an atmosphere of oxygen (diluted with nitrogen), at temperatures between — 50° and 120° Fahrenheit, and exposed to the rays of the sun.

"The protoplasm which is the real body of the plant cell, to which the most important incidents of its life are attached, is a sticky, colorless, transparent mass, always containing water, and

[5] Harland Coultas: ant, an Illustration of the Organic Life of the Animal."

often drops of fat, crystals of carbonate of lime, and grains of starch. This protoplasm consists of inorganic and of organic matter, under which lattter term. the albuminous materials and their products of modification or decomposition play an important part. The air-dried substance of the *Plasmodium septicum* contains, according to Dr. Rodewald, 29, 25 p. c. of ash, consisting of:

	P. C.
Lime,	64.34
Magnesia,	0.71
Potash,	1.42
Soda,	0.18
Oxide of iron,	0.13
Carbonic acid,	36.02
Phosphoric acid,	6.49
Sulphuric acid,	0.42
Chlorine,	0.21
	99.93

The ether extract of the protoplasm contains:

	p. c.
[6] Paracholesterin,	22.00
Fatty acids,	3.00

Leithicin, traces of glycerin, and resins.

Besides there are present hydro-carbons, albuminous matter, and other nitrogenous bodies, which are more products of decomposition of albumen.

"There are certainly disastase, fat emulsion-making ferments contained in it, besides plastin and albumen substance like fibrin, Myosin, Quenin, Sarkin, Xanthin, Carbonate of Ammonia, Butyric acid, and Coneisinic acid.[7]

All these substances are composed of carbon, hydrogen, oxygen and nitrogen, with small quantities of sulphur and phosphorus, etc.

[6] Paracholesterin is one of the isomeric alcohols of Cholesterin (Liebig's Annalen, Vol. 207, p. 229).

[7] Husemann, Pflanzenstoffe, 2d Ed., 1884.

A mean of two analyses of the albumen or stored food of the plant seed is :[8]

Carbon	53.21
Hydrogen	7.29
Oxygen	22.85
Nitrogen	15.78
Sulphur	.40
	99.43

The same elements enter into the composition of the protoplasm of animals, as may be seen from Robin's analysis of the amniotic fluid of a fecundated ovum, etc., etc. (Flint's Text Book of Physiology, p. 903).

In the main these elements of the protoplasm of both plants and animals may be regarded as hydro-carbons, or hydrogen and carbon with occasional nitrogen and oxygen, drawn from the soil and air into the plant, and from the plant into the animal, and expended by both as fuel, producing the motor known as vital force. It has been said that in the main constituent of this material were hydrogen and carbon, but it was not implied that these were the only constituents of this substance.

What we call " nature " acts in this as in so many other instances as a prudent speculator who will not entrust all his eggs to one basket. An analysis, however crudely conducted, will detect in the simplest food-stuff of plants, besides hydrogen and carbon, sulphur, phosphorus, chlorine, potassium, sodium,and calcium. More careful analysis of larger amounts of material will detect the presence of many other and rarer substances, iron, copper, iodine, etc. Still more delicate tests increase the number of chemical elements which are present, either as accessories, as " rare " or " very rare " concomitants.

It is not an unjustifiable generalization to say that the number of chemical elements contained in the " albumen " of a seed-sac or the amniotic fluid of a mammal increases with every increased

[8] See Dragendorff's Plant Analysis, p. 288, N. Y., Vail & Co., 1887.

effort to detect them, so that it is not at all unreasonable to conclude that practically the whole category of elements forming the superior part of the earth's crust, or floating as gases in the atmosphere, is represented in this material.[9]

Under the conditions of temperature, actinism (or the chemical effect of the sun's rays), barometric pressure, and constitution of the atmosphere and soil, the organic beings of our globe draw on their protoplasm for certain elements in excess of others, because under these conditions the decompositions and recompositions which take place are suited to maintaining life ; but, should any or all of these conditions change ; should the barometric pressure caused by the attraction of gravitation increase or diminish ; should the proportion to each other of the constituents of the atmosphere suffer any marked variation ; in any of these cases the present equilibrium would be disturbed ; the oxidation and deoxidation of the materials now employed as the bases of organic structure would evolve and absorb too many or too few heat-units for the present system of life, and either this latter would change, giving rise to new animals and plants, or the materials which would be selected from the protoplasm for assimilation would be other than carbon and hydrogen, thus giving rise to different structures, composed of different materials, and behaving differently to heat and cold and chemical reagents.

In a paper on Animal Protoplasm, read before the Am. Phil. Soc., and printed in the AMERICAN NATURALIST in 1879, I considered the effect of changes of this kind on animals, pointing out that life being incomprehensible except as we could measure or weigh the phenomena which accompanied it, and these phenomena being such as would naturally occur among the substances by which we are surrounded, there was nothing to preclude the idea of living things colder than frozen mercury or hotter than molten platinum. This is true of the plant as well. As long as

[9] It would be apposite here to refer to Crooke's beautiful hypothesis of the evolution of the elements to show that each so-called element is probably only one physical manifestation of the same matter, made permanent by the peculiar conditions which surrounded it at its genesis, and that therefore in any mass of matter we have one or more forms of the single matter which constitutes all things. But this would lead us astray from the argument in hand.

force and matter exist, there is no reason to deny that they may produce the root and stem and leaves of the plant, of materials which will enter into the cycle of changes now effected at greatly higher or lower temperatures, thus preserving the rate and kind of change, while altering the materials which undergo it. This result would be a metasomatic evolution. On the other hand, the greater rapidity or slowness of these reactions might change the character of the organism, while the material remained unchanged, which would produce a metagenetic evolution. Or both substance and rate might alter, giving rise to an entirely different world, with different organisms and different processes, and as far from our present world as is the spiritual from the material.

To resume the case: 1. A careful study of the modes of growth in the three kingdoms of nature—mineral, plant, and animal—shows that there are strong analogies between them, the divergence being progressive in the order named, though many of the strongest characteristics, such as sensation, etc., of the highest or animal kingdom, are of such a kind that we are prevented from knowing their presence or absence in the other kingdoms.

2. The characteristics common to all three kingdoms are the presence of force; its action upon matter; and its renewal by the change of one form of matter to another, in the course of which energy is manifested.

3. In the crystal kingdom the restrictions on the existence and growth of the individual being least, and the variations of conditions and environment in which existence is possible, greatest, the individuals are more numerous and their composition more diverse, all of the known and unquestionably many as yet unknown elements uniting to form them.

4. As to the plant and animal kingdom the cycles of changes are based for the most part upon the disunion and separate combinations of carbon and hydrogen, because, at the existing temperature, pressure oxygen-atmosphere, and sunlight, these changes can be produced to the greatest advantage of existing kinds of living things and life forces.

5. With a much hotter or colder earth; an earth where the weights of bodies were much greater or much less they are now; an earth not surrounded by an ocean of oxygen gas; or an earth deprived of the chemical force of our sun; some changes would be made in the modes in which life is perpetuated now, to suit these changed conditions of the planet, *but it is extremely unlikely that life would be extinguished by them, unless the conditions changed too suddenly.*

6. The nature of these changes would be either: (a) to keep foreign matter flowing through the living body at about the rate it flows now, in which case the hydro-carbons would give place to some other group or groups of chemical elements to supply the framework of the plant or animals; or, (b) the rate of change of these groups of atoms being very much altered, the attributes of the living things of which they formed a part would be very much changed; or, (c) if both the elements themselves and the rapidity with which these resolved themselves into new combinations were changed, the diversity of the living things and of the world itself would be so different from what they are now that we have no means of forming the least conception of them.

7. But in no one of these cases is it likely that *life* would become extinct, though the present relations to each other of the three kingdoms of nature would cease to be.